SEMI-ANNUAL REPORT ON THE PROGRAM OF RESEARCH IN SPACE-RELATED SCIENCES ESTABLISHED AT THE UNIVERSITY OF FLORIDA UNDER NASA RESEARCH GRANT NsG 542

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INTRODUCTION

This document constitutes the semi-annual report for the NASA-sponsored institutional program in space-related sciences at the University of Florida. The program has been in operation since November 1, 1963, and to date has involved a total of 28 different projects in 11 science and engineering departments of the University. The present report concerns those projects that were active during the period May 1, 1966 to October 31, 1966. Descriptions of the work of the individual projects were prepared by the appropriate principal investigators and edited and assembled under the supervision of the Chairman of the NASA Steering Committee of the University of Florida.

PROJECT A02

OBSERVATIONS WITH THE ARECIBO 1000-FOOT RADIO TELESCOPE

1. Department: Physics and Astronomy

2. Principal Investigator: T. D. Carr

3. Background: The primary objective is to utilize the radio telescope at the Arecibo Ionospheric Observatory in Puerto Rico to supplement the radio astronomy program at the University of Florida. Investigations to date have been principally on the planet Jupiter. Three series of observations of the Jovian synchrotron emission at 430 Mc/s have been made at Arecibo. The observations have proven that the beaming effect, which had previously been observed only at higher frequencies, extends down to 430 Mc/s. Attempts to utilize these measurements to improve the accuracy of our knowledge of the rotation period of Jupiter's magnetic field have been unsuccessful because of insufficient data. However, these studies have lead to important developments regarding the rotation period, which were based upon a re-examination of other data.

4. Progress from May 1 to October 31, 1966: Data reduction for the series of observations of Jupiter made at Arecibo at 430 Mc/s by Gulkis and Carr in October 1965 was completed. As indicated in the previous observations at Arecibo by Tiberi of the University of Florida, a slight but definite correlation of intensity with System III central meridian longitude was found. By measuring the drift in the peak of the curve of intensity vs. System III longitude, it was again possible to compute the mean correction to the assumed rotation period. Unfortunately, there were still not enough observations to yield the desired precision. There was, however, the suggestion of a drift corresponding to a rotation period about half a second longer than that of System III. Subsequently, a thorough re-evaluation of all available measurements of the Jovian rotation period at both decimeter and decameter wavelengths was made by Gulkis and Carr. The conclusion was reached that Jupiter's magnetic field rotates with an essentially constant period which is about 0.3 second longer than the System III period. It was suggested that a previously unexplained change in rotation period which had been observed at 18 Mc/s was part of a regular oscillation about the true mean value. It was further suggested that the period of this oscillation is 11.9 years, the orbital period of Jupiter. The effect was attributed to the changing geometrical relationship between Jupiter and the earth, and is believed to be indicative of a narrow beaming of the decameter wavelength radiation. Several lines of evidence were found to support these suggestions. The results were published recently in Science (see publication list).

On the basis of the various observations of Jupiter made by University of Florida personnel at Arecibo at 430 Mc/s, it was possible to establish an empirical relationship between the quantity of data obtained and the resulting accuracy of the rotation period measurement. This relationship will be used as a guide in designing future observational programs of Jupiter at Arecibo.

5. Publications and Papers Presented:

S. Gulkis and T. D. Carr, "The Radio Rotation Period of Jupiter," Science, 154, 257-259, 1966.

S. Gulkis and T. D. Carr, "Asymmetrical Stop Zones in Jupiter's Exosphere," Nature, 210, 1104, June 1966.

S. Gulkis and T. D. Carr, "The Radio Rotation Period of Jupiter," paper presented at the meeting of the American Astronomical Society, Cornell University, July 26, 1966.

T. D. Carr, "Jupiter at Radio Frequencies," colloquium talk at Louisiana State University at New Orleans, August 3, 1966.

6. Budget for Period May 1 to October 31, 1966:

Salaries	$5,330.80
Expenses	415.61
Capital Equipment	1,507.47
Total expenditures	$7,253.88

PROJECT A03

AN INVESTIGATION OF THE LOW-FREQUENCY EXTREME
OF THE JOVIAN RADIO SPECTRUM

1. Department: Physics and Astronomy

2. Principal Investigator: Alex G. Smith

3. Background: This project involves the operation of a small radio observatory in a carefully selected valley in the Chilean Andes near the town of Huanta. Selection of this site was on the basis of isolation and shielding by the surrounding mountains. The principal objective of the station is the low-frequency radio observation of the planets Jupiter and Saturn under conditions as free as possible of both natural and man-made interference. The station is maintained and operated throughout the year by Sr. Vladimir Papic and two Chilean assistants. During the report period three members of the University of Florida group, C. N. Olsson, Alex G. Smith and Miss D. L. Smoleny, spent time at the Huanta station improving the instrumentation, reducing records, and erecting new antennas.

4. Progress from May 1 to October 31, 1966: During May and June two new antennas were added to the equipment; an 18 Mc/sec broadside array for making precision flux density measurements, a 22 Mc/sec interferometer, and a 10 Mc/sec interferometer.

Another major improvement was made during this period with the replacement of the old equipment shelter (a war-surplus ambulance) by a permanent adobe building. This new structure affords far greater protection to the radio equipment.

Observation of Saturn was begun on the 24th of June on all channels and thus far a few possible Saturnian events have been recorded. The monitoring of Jupiter was started during the latter part of October, when the planet's position became favorable for the southern hemisphere.

In July, when the French detonated a nuclear device in the Pacific, all channels were monitored in hope of detecting possible ionospheric effects such as those which accompanied the Starfish explosion in 1962. In this case the results were negative, but the weapon was of very small yield. Future tests of this kind will also be monitored.

The 5 Mc/sec and 10 Mc/sec data from the 1965 apparition have been used to evaluate the flux density at these frequencies. The 18 Mc/sec data have been reduced at the University of Florida and again, as in the past, the peak probability of receiving Jupiter at Huanta was twice that at the larger Maipu station in central Chile; at Huanta the probability of receiving source A was 0.33, against a value of 0.14 at Maipu. It is significant that in both cases these values are well below the 1964 levels, as Jovian emission apparently continues to follow an 11- or 12-year cycle in synchronism with either the sunspot cycle or the planet's orbital position. The superior Huanta statistics are of obvious value in studying such long-term trends.

5. Publications:

A. G. Smith, G. R. Lebo, C. N. Olsson, W. F. Block, N. F. Six, and T. D. Carr, "Jovian Rotation Periods and the Origin of the Decametric Burst Structure," Proceedings of CALTECH-JPL Lunar and Planetary Conference, California Institute of Technology, 128-133, 1965.

A. G. Smith, W. F. Block, W. A. Morton, G. R. Lebo, and T. D. Carr, "Influence of the Terrestrial Environment on the Temporal and Statistical Characteristics of Jovian Decametric Radiation," Radio Science, 1 (New Series), 1167-1171, 1966.

6. Budget for Period May 1 to October 31, 1966:

Salaries	$ 9,739.00
Expenses	5,936.00
Capital Equipment	144.00
Total expenditures	$15,819.00

PROJECT A05

NUCLEAR ASTROPHYSICS

1. Department: Physics and Astronomy

2. Principal Investigator: F. E. Dunnam

3. Background: This research represents an attempt to duplicate in the laboratory some of the nuclear reactions that are believed to take place in stellar interiors. Using standard techniques of nuclear physics, we measure various reaction parameters (cross-sections, for example) in order to determine the relative probability of occurrence of the several possible nuclear reactions. Eight or more classes of nuclear processes are believed to occur during the life of a star. For the past year we have confined our work to a class of nuclear reactions which occur fairly early in stellar evolution: "helium burning" and the synthesis of elements by alpha particle bombardment. The University of Florida 4-MeV Van de Graaff accelerator produces the alpha particles; gamma rays from the nuclear reactions are detected with sodium iodide scintillators.

4. Progress from May 1 to October 31, 1966: Natural-parity excited states in S^{32}, S^{34}, Ar^{36}, and Ar^{38} have been studied through the reactions $Si^{28,30}(He^4,\gamma)S^{32,34}$ and $S^{32,34}(He^4,\gamma)Ar^{36,38}$. Both "natural" and isotopically-enriched targets were used; thin layers of the material were evaporated onto copper backings, which were then bombarded with He^4 ions from the accelerator. Helium ion beam currents were approximately 2 microamperes and target thickness averaged 12 keV. With Si^{28}-enriched targets, we found five resonances between 3.76 and 4.20 MeV, corresponding to excitations in S^{32} at 10.23, 10.31, 10.35, 10.41, and 10.45 MeV. The 10.23- and 10.45-MeV levels are 2+ in spin and parity; the 10.35-MeV level is 1-. Using S^{32}- enriched targets, 12 new resonances were discovered for an incident He^4 energy range of 3.2 to 4.2 MeV, only one of which was observed with natural target material. The other 11 resonances thus represent energy levels in Ar^{36} at excitations of 9.56 to 10.30 MeV. Spins and parities of these new levels are presently being determined, after which the data will be analyzed to determine the radiative width at each level.

A new method of evaporating sulfur onto silver backings has been developed; the compound AgS is found to withstand intense ion beam bombardment without breaking down. Much trouble had been experienced with the previously-used compounds, CuS, ZnS and CdS. The next group of experiments will utilize enriched isotopes of neon and argon as targets. The target gases have already been obtained and arrangements have been completed for adsorbing the material onto suitable backings. We are

also completing the target chamber and associated apparatus for studying the $C^{12}(\pi,\gamma)O^{16}$ reactions mentioned in an earlier report. Finally, recent installation of a new ion source on the accelerator should permit us to obtain useable intensities of doubly-ionized helium ions, allowing us to extend all our previous measurements from 4 to 8 MeV bombarding energy.

5. Publications and Dissertation:

P. N. Carlton, "Excited Nuclear States of Sulfur and Argon Produced by 3-4 MeV Alpha Particles," Ph.D. Dissertation, University of Florida, June, 1966.

P. N. Carlton and F. E. Dunnam, "Nuclear Levels in Sulfur Excited by the (He^4,γ) Reaction," Joint meeting of American Physical Society, Sociedad Mexicana de Fisica, and Canadian Association of Physicists, Mexico City, August 29-31, 1966, Bul. Amer. Phys. Soc., 11, 737, 1966.

F. E. Dunnam and P. N. Carlton, "Level Structure in Ar^{36} and Ar^{38} from the $S^{32,34}(He^4,\gamma)Ar^{36,38}$ Reactions," Joint meeting of American Physical Society, Sociedad Mexicana de Fisica, and Canadian Association of Physicists, Mexico City, August 29-31, 1966, Bul. Amer. Phys. Soc., 11, 737, 1966.

6. Budget for Period May 1 to October 31, 1966:

Salaries	$ 5,780.00
Expenses	1,738.95
Capital Equipment	2,910.95
Total expenditures	$10,429.90

PROJECT A06

MAGNETOFLUIDMECHANICS

1. Departments: Aerospace Engineering and Electrical Engineering

2. Principal Investigators: M. H. Clarkson and B. E. Mathews

3. Background: The initial purpose of this project was to develop diagnostic techniques applicable to RF-generated plasmas. Work in this connection was centered on the development of electrostatic probes for use in low-density plasmas, and on spectroscopic techniques for use in plasmas at atmospheric pressure. With the development of these techniques, emphasis has gradually shifted toward obtaining a better understanding of the electrodeless discharge.

4. Progress from May 1 to October 31, 1966:

A. Low-Density Plasma Diagnostics. (The low-density plasmas refer to pressure ranges of from 1 to 500 microns of mercury.) Since the last progress report, further investigations of the electrodeless discharge have proceeded from both an experimental and theoretical basis. An attempt was made to use a magnetic probe to measure the phase shift and attenuation of the applied field within the plasma as a means of determining the complex conductivity of the plasma medium. The procedure was not completely successful, as impossibly high values of attenuation were measured. This result was attributed to a disruption of the normal diffusion process by the introduction of an additional boundary into the discharge volume, an assumption which was investigated by the use of probe techniques and found to be correct. This work resulted in a master's thesis by Mr. Walter Demske.[1] The result is not unique to the electrodeless discharge, but would apply to any diffusion-controlled discharge, and should be considered in interpreting any magnetic probe data.

The results of previously reported probe measurements[2] have been published in the AIAA Journal.[3] These results raise some very interesting questions regarding the theory of Eckert.[4] Eckert assumes that ionization occurs in a region near the discharge wall, implying higher temperatures near the wall and a flat-topped distribution of number density. The probe data indicate a uniform temperature, and a number density distribution which implies a uniform production of ionization as well. It is our opinion that the uniform temperature distribution is a result of electron-electron interaction usually neglected for partially ionized plasmas. A preliminary analysis of the steady-state temperature distribution, including electron-electron interactions from the approach of Shkarofsky, et al.,[5] indicates that the temperature distribution is essentially uniform even though the

input power flux is strongly dependent on position. If subsequent analysis bears this out, it will lead to a decoupling of the transport equations and Maxwell's equation, allowing a relatively simple calculation to be made of power input and plasma impedance. This would then allow a calculation of maximum power input, and the proper design of an electrodeless discharge for maximum efficiency coupling from the power source to the discharge.

Another method of measuring plasma properties, involving a plasma-loaded wave guide, has been under consideration for some time. This work is essentially an analysis of the proposal by Keenan and Kelly.[6] The approach taken in this problem is to solve for standing wave patterns in a plasma-loaded wave guide in which there is a variation in electron number density in the axial direction. This work is the subject of a dissertation by Mr. Ralph Kinney, now nearing the final stages. Most of the mathematical techniques for solving the propagation of electromagnetic waves in wave guides filled with an inhomogeneous medium have been resolved, and a number of results have been obtained. Preliminary indications are that the techniques described in reference 6 may give erroneous results.

As a means of checking energy transport from the plasma to a wall in RF discharges, an experiment is being designed in which the heat transfer rates to the wall of a discharge will be measured as a function of power input, pressure, and axial location in the discharge.

B. Plasma Diagnostics at Atmospheric Pressures. Since the last progress report, two papers on spectroscopic diagnostics of atmospheric-pressure electrodeless discharges have come to our attention.[7,8] The results of the two papers are in good agreement. They give an off-axis temperature peak of approximately 9500°K with an axis temperature slightly above 9000°K. These results are very similar to results previously obtained in this laboratory prior to the use of a correction for depth of field (discussed in last report). A personal communication with Mr. P. D. Johnston was made to obtain the optical geometry of his experimental apparatus. We plan to run a defocusing correction for his experiment to see if the off-axis peak in temperature is still obtained.

The plasma generator has been redesigned to utilize a nominal 5KW power supply. An optical bench has been built to facilitate optical alignment. The generator was obtained from Government surplus, and the past month has been spent restoring this equipment to operating condition. A plasma has been obtained using the new equipment, but no spectroscopic work has yet been done on this apparatus. A laser has been obtained to facilitate optical alignment.

The discrepancy between our work and the two papers previously mentioned could be due to the fact that defocusing was not considered by them. It may also be due to the difference in power supplied to the plasma. Since the other researchers operated at higher powers than we were previously able to achieve, it is possible that we will find this off-axis peak with the new experimental set-up.

An experimental facility to investigate the radiation from an electrodeless discharge from pressures in the micron range up to atmospheric pressure has been designed and is being constructed. We will investigate the absolute intensity of line radiation for as many lines as Olsen[9] has transition probabilities available, in order to see how the distribution of electron energies varies as the discharge becomes a nonequilibrium one. The implication here is that the plasma is in L. T. E. at atmospheric pressure. Johnston[7] argues that this is the case, and we tend to agree based on the work in the laboratory. In any event it has not been rigorously shown that this is true.

5. Publication and Thesis:

W. L. Demske, "An Investigation of Electron Diffusion in an Electrodeless Discharge," Master's Thesis, University of Florida, August, 1966.

D. R. Keefer, M. H. Clarkson, and B. E. Mathews, "Probe Measurements in an Electrodeless Discharge," AIAA Journal, October, 1966.

6. Budget for Period May 1 to October 31, 1966:

Salaries*	$22,393.75
Expenses*	432.80
Capital Equipment	200.00
Total expenditures	$23,026.55

*In addition to the above, the Department contributed:

Salaries	$ 2,292.01
Expenses	258.20
Total expenditures	$ 2,550.21

7. References:

1. Demske, W. L., "An Investigation of Electron Diffusion in an Electrodeless Discharge," Master's Thesis, University of Florida, August, 1966.

2. Keefer, D. R., Clarkson, M. H., and Mathews, B. E., "Probe Measurements in an Electrodeless Discharge," presented at the AIAA Plasmadynamics Conference, Monterey, California, March 2-4, 1966.

References Continued:

3. Keefer, D. R., Clarkson, M. H., and Mathews, B. E., "Probe Measurements in an Electrodeless Discharge," AIAA Journal, October, 1966.

4. Eckert, H. W., "Diffusion Theory of the Electrodeless Discharge," Convair Scientific Research Lab., San Diego, California, Research Rept. 9 (1961).

5. Shkarofsky, I. P., Johnston, T. W. and Bachynski, M. P., The Particle Kinetics of Plasmas, Addison-Wesley, 1966.

6. Keenan, P. P. and Kelly, F. L., "Microwave Diagnostic Studies in Electrodeless Discharge Plasmas," IEEE Trans. on Nuclear Science NS-11, No. 1 (1964).

7. Johnston, P. D., Physics Letters, 20, 499, 1966.

8. Gol'dfarb, V. M. and Dresvin, S. V., Teplofizika Vysokikh Temperatur, 3, 333, 1965.

9. Olsen, H. N., J. Quant. Spectrosc. Radiat. Transfer, 3, 305, 1963.

PROJECT A09

FLUIDS IN LOW GRAVITATIONAL FIELDS

1. Department: Engineering Science and Mechanics

2. Principal Investigators: J. Siekmann and L. M. Habip

3. Background: Research has been directed and continued (cf. semi-annual report of April 30, 1966) along the following lines:

a. The relative equilibrium configuration and stability of a rotating finite fluid mass under capillary forces only at the axis of another rotating fluid, including the effect of an electric field.

b. The dynamic response of a wetting liquid enclosed in a rotating tank in a zero-g environment to various disturbing forces.

c. The hydroelastic solution for the sloshing of a liquid with a curved surface in a cylindrical tank having a flexible bottom.

4. Progress from May 1 to October 31, 1966:

a. A paper dealing with results of this study has been presented at the 5th U. S. National Congress of Applied Mechanics, University of Minnesota, June 14-17, 1966. (An abstract appears on page 764 of the Proceedings.) An extended version of the paper has been accepted for publication in the open literature (see below).

During this period, L. M. Habip investigated the capillary stability of a rotating dielectric liquid cylinder in an electric field. Results will be communicated at the Southeastern Symposium on Missile and Aerospace Vehicle Sciences of the American Astronautical Society, to be held at Huntsville, Alabama, December 5-7, 1966 (see below).

b. The general oscillation problem of the bubble surface has been studied for the so-called "elliptic case." Analytical and numerical results will be communicated in a forthcoming paper by S. K. Pao and J. Siekmann. At present, the so-called "hyperbolic case" is under investigation.

c. The problem of liquid sloshing in a cylindrical tank with a flexible bottom [(A) thin elastic plate, (B) membrane] has been solved by developing a new approach. The differential equation governing the bottom condition has been transformed into an integral equation, and the latter solved by functional approximations. Mathematically, this method is equivalent to approximating the kernel of the integral equation by degenerated kernels. Results will be communicated in a forthcoming master's thesis by S. C. Chang, and in a paper (dealing with the plate case) to be read at the above-mentioned Southeastern Symposium (see below).

5. Publications and Thesis:

L. M. Habip, "On the Mechanics of Liquids in Subgravity," Astronautica Acta, 11, 401-409, 1965.

L. M. Habip, J. Siekmann, and S. C. Chang, "On the Shape of a Rotating Liquid Drop in an Electric Field," Acta Mechanica, in press.

L. M. Habip, "Capillary Stability of Rotating Dielectric Liquid Cylinder in an Electric Field," Proceedings of Southeastern Symposium on Missile and Aerospace Vehicle Sciences, American Astronautical Society, Huntsville, Alabama, 1966, in press.

S. C. Chang, "On Subgravity Hydroelastic Sloshing of a Liquid with a Curved Free Surface in a Cylindrical Tank having a Flexible Bottom," Master's Thesis, University of Florida, December, 1966.

J. Siekmann and S. C. Chang, "On Liquid Sloshing in a Cylindrical Tank with a Flexible Bottom," Proceedings of Southeastern Symposium on Missile and Aerospace Vehicle Sciences, American Astronautical Society, Huntsville, Alabama, 1966, in press.

6. Budget for Period May 1 to October 31, 1966:

Salaries	$5,916.62
Expenses	111.69
Capital Equipment	1,970.08
Total expenditures	$7,998.39

PROJECT A10

STUDY OF GRAIN BOUNDARY PROPERTIES AND THE ROLE OF MECHANICAL STRESSES IN THE PROCESS OF HIGH TEMPERATURE OXIDATION

1. Department: Metallurgy and Materials Engineering

2. Principal Investigators: F. N. Rhines and J. E. Lemons, Graduate Assistant

3. Background:

A. Introduction. Industrially, metals find many uses that require a variety of special properties. Metallic grain size must be accurately controlled to assure reliability in most applications. Although grain size control finds extensive use, the fundamental nature of the grain boundary per se, and its properties within the polycrystalline aggregate, are not well understood. The role of grain boundaries as a transport path during high temperature oxidation was investigated and explained as Phase I of this project. Investigations are now being continued to study the grain boundary as it affects the mechanical properties of metallic solid solutions.

Initial investigations have shown that Brinell hardness is directly proportional to grain boundary area for seven alloys spanning the complete range of alpha brass. For each alloy, a special experimental technique permits the separation of (1) hardness attributed to grain boundary area, and (2) average single crystal hardness. The latter is measured by extrapolating the hardness versus grain boundary area relation to zero grain boundary area. This hardness value at zero grain boundary area may be thought of as a single crystal hardness that has been averaged over all possible orientations. The hardness contribution of grain boundary area is obtained by subtracting the hardness at zero grain boundary area from the total hardness of a polycrystal. Thus the grain boundary area hardness contribution is measured by the slope of the hardness versus boundary area relation.

B. Summary of Past Investigations of Grain Boundary Properties in Alpha Brass (Phase II). Grain boundary and average single crystal hardness as a function of composition: Hardness obtained at zero grain boundary area is independent of composition change, while the slope of the hardness versus grain boundary area relation increases slowly at first with increasing zinc content, and then rises to a sudden peak at approximately 30w/o zinc.

Grain boundary and average single crystal hardness as a function of temperature: Hardness versus grain boundary area relations were investigated at 77, 573 and 873°K. Hardness is directly proportional to grain boundary area at each of these temperatures. The hardness at zero grain boundary area decreases almost regularly with rising temperature. This is true also of the grain boundary contribution to hardness. The maximum in grain boundary hardness contribution at 30w/o zinc became less pronounced at 573°K and disappeared completely at 873°K.

Measurements of relative grain boundary energies in alpha brass: (a) Copper and all alpha brass alloys were subjected to mercury embrittlement along grain boundaries at 473°K. Penetration depth was found to maximize at approximately 30w/o zinc. Accordingly, the grain boundary energy maximizes at 30w/o zinc. (b) Dihedral angles of lead particles along grain boundaries of alpha brass alloys were measured as a function of composition and heat treating temperature. Experimental scatter was so great that no clear-cut analysis could be made. This investigation is being improved and repeated under Phase III research topics.

Microstructure of the grain boundary: Electron microscope replicas were taken of random grain boundaries at each composition in the alpha brass series. Magnifications were 5,000 X through 30,000 X. Analysis of these micrographs showed no anomalous characteristics.

4. Progress from May 1 to October 31, 1966: The hardness of pure copper versus grain boundary area survey was completed. Hardness was found to be directly proportional to grain boundary area. The zero grain boundary area intercept was slightly lower than those for alpha brasses. The hardness contribution of grain boundary area was also less than found for any of the brasses. Hardness versus grain boundary area relations were also measured at 77, 573 and 873°K, with the results showing a regular similarity to the brass studies.

Speculation as to the validity of the average single crystal hardness extrapolation was tested by measuring the microhardness of twenty-five equal-sized grains at each composition. The general trend of average microhardness measured as a function of composition was in good agreement with the zero grain boundary area hardness results, in that average hardness of the grain material (without grain boundaries) does not show a maximum at 30w/o zinc.

The survey of mechanical properties was extended to include stress versus strain relations for all of the alpha brass alloys previously investigated. Stress versus strain curves were determined by compressing solid 5/16-by 3/4-inch cylindrical specimens. At each composition, curves were established as a function of grain boundary area so that comparisons could be made with hardness versus

grain boundary area relations. The area under a predetermined portion of the stress versus strain curves showed a regular behavior in the composition region 20-35w/o, in that the area under the curve is a linear function of grain boundary area. Comparisons between hardness versus grain boundary area and area under the stress-strain curve versus grain boundary area revealed similar trends. Many problems were encountered: (1) exterior surface effects seemed to overshadow grain boundary properties at the lower zinc compositions; (2) specimen ends or load cell surfaces were not perfectly parallel, causing an unnatural distortion of the specimens; and (3) the grain boundary area of the specimens tested did not extend over a wide enough range. Hopefully, this investigation can be extended.

5. Publications: Mr. Lemons presented a paper on May 6, 1966, at the Conference on Current Metallurgical Research at Cape Kennedy. The paper summarized investigations conducted through that date.

6. Budget for Period May 1 to October 31, 1966:

Salaries	$1,472.00
Expenses	27.00
Capital Equipment	658.00
Total expenditures	$2,157.00

PROJECT A13

A STUDY OF FLUID (INCLUDING PLASMA) STATES OF MATTER

1. Department: Physics and Astronomy

2. Principal Investigators: A. A. Broyles and C. F. Hooper

3. Background: This program is developing methods of computing thermodynamic and other properties of fluids, including plasmas. Specifically, we are concerned with the equation of state, the scattering intensities of x-rays and neutrons off of fluids, and the shape and width of spectral lines from hot plasmas. In addition to plasmas, we are considering liquid noble gases and liquid alkali metals. Our studies started with classical systems, since they form the high-temperature limit of quantum systems. Techniques developed for these systems have been extended to quantum mechanical systems by working down from high temperatures to low. We are also computing the properties of the ground state of liquid helium.

4. Progress from May 1 to October 31, 1966: We have continued our calculations of pair potentials from liquid krypton scattering data for neutrons at various temperatures and densities. This work is still in progress.

An IBM 709 program is being constructed to obtain the ground state wave function for liquid helium. It solves the equation obtained by Kiroike by minimizing the energy, using a trial wave function in the form of a Boltzmann factor with effective pair potentials. This equation involves the assumption that the bridge diagrams in the Mayer cluster expansion for the radial distribution function can be neglected. We are developing means for avoiding this last approximation, which is known to be poor in certain applications of interest.

We have obtained effective pair potentials for ideal Bose and Fermi gases that, when included in a classical Boltzmann factor, give a good approximation to the Slater Sum. In the case of the Fermi gas, we have covered the range from absolute zero to infinite temperature. The energies computed from these effective potentials are in error by, at worst, 8%; over most of the range the error is much smaller than this. Effective potentials for the quantum, non-ideal electron gas at high temperatures and high densities have also been obtained to give approximate Slater Sums. This work is continuing and the methods are being improved.

Calculation of the radial distribution function for the classical electron gas has been completed for the temperature parameter 0 down to 0.4, and a paper covering this work has been approved for publication in the Journal of Chemical Physics.

Our work on the calculation of electric microfields in plasma has progressed to the point where final results are being collated and evaluated. Preliminary results indicated that the formalism and calculational technique that we have developed is considerably more efficient than other previous approaches, in that it is valid for a much wider range of temperature-density parameters. The method is also more flexible, since it can readily be adapted to strictly quantum mechanical plasmas with the aid of effective potentials.

5. Publications:

A. A. Broyles and A. A. Kahn, "Interatomic Potential of Krypton," American Physical Society, Washington Meeting, April 26-29, 1966, Bul. Amer. Phys. Soc., 10, 458, 1966.

A. A. Kahn and A. A. Broyles, "Interatomic Potentials and X-ray Diffraction Intensities for Liquid Xenon," J. Chem. Phys., 43, 43, 1966.

A. A. Kahn and A. A. Broyles, "Effective Interatomic Potentials for Liquid Helium Above and Below the λ Point," Phys. Rev., 139, A1805, 1966.

D. D. Carley, "Recent Studies of the Classical Electron Gas," J. Chem. Phys., in press.

6. Budget for Period May 1 to October 31, 1966:

Salaries	$ 5,781.68
Expenses, including computing	9,246.50
Total expenditures	$15,028.18

PROJECT A15

MOLECULAR BEAM INVESTIGATION OF SURFACE REACTIONS

1. Department: Chemistry

2. Principal Investigators: E. E. Muschlitz, Jr.; J. T. Scott, Post Doctoral Fellow; and R. N. Coltharp, Graduate Assistant

3. Background: The molecular beam technique has a number of distinct advantages when applied to the problem of surface reactions. The surface under investigation may be oriented with respect to the direction of the incident molecules, the angular distribution of the particles leaving a hot surface may be studied, and the identity of any active species (excited molecules, atoms, or free radicals) produced may be determined before they are destroyed by gas phase or wall collision. Very few studies along these lines have so far been attempted. Yet information which may be obtained is of considerable value with respect to a number of practical problems arising in the space program, particularly the problem of re-entry. The method is capable of yielding direct information regarding such surface properties as catalysis, residence time, and accommodation efficiency.

4. Progress from May 1 to October 31, 1966: The experimental arrangement consists of a multi-channel molecular beam source, a chopper to modulate the beam intensity, a tungsten ribbon target and an Electronics Associates, Inc. quadrupole mass spectrometer used as the molecular beam detector. This detector can be rotated about the target to determine the angular distribution function of molecules reflected from the tungsten surface. The output from the mass spectrometer is amplified with an electrometer and the in-phase component of the signal at the modulating frequency (usually 90 c.p.s.) is detected with a narrow-band, lock-in amplifier.

A preliminary search for reflected hydrogen molecules, with a hydrogen molecular beam directed at the target gave no result. This was felt to be due to the low signal-to-noise ratio of the detecting system. Measurements of the direct incident beam (with no target in place) originally showed a signal-to-noise ratio of about 10, which is clearly too low to allow a reflected signal, which will have particle densities not greater than one per cent of the incident beam, to be detected. This noise arises from components of the signal from hydrogen in the background gas, which are at the modulating frequency and in phase with the beam.

Several modifications have been made or are in progress to increase the signal-to-noise ratio. First, the Q-factor of the detecting system has been raised from 25 to about 36 by the addition of an active twin-T filter network, tuned to 90 c.p.s. This represents an equivalent band-width of about 2 cycles per second. Also, additional circuitry has been added to the lock-in amplifier to increase the time constant of its low frequency cut-off filter from 10 seconds to 30 seconds, and the output is integrated over several minutes with the aid of an integrator mounted on the chart recorder.

Second, attention has been paid to the quadrupole mass spectrometer to reduce the noise level as much as possible. The ion-source has been re-designed, and modifications introduced to decrease the volume available to general background gas in the ionization region and to increase the efficiency of extraction of ions formed in the molecular beam.

The foregoing improvements have raised the signal-to-noise ratio on the incident beam to about 50. Further improvement is expected by the reduction of the background hydrogen pressure by the addition of a 2,000 liter per second titanium sublimation pump to the system, which is currently pumped with a 4,000 liter per second oil diffusion pump baffled down to 2,000 liter per second.

Should the resulting signal-to-noise ratio still be insufficient to allow detection of scattered molecules, further improvement is available by a reduction of the target-detector distance, at the expense of angular resolution. The distance is now 35 cm., and a reduction by a factor of two should give a four-fold increase in signal.

5. Publications: No publications have resulted as yet from this research. The preliminary results will be discussed at the December Symposium on Fundamentals of Gas-Surface Interactions, to be held in San Diego, California. This research was started as an entirely new program and has received no support from other agencies. Construction of the complex apparatus required an initial period of two years. These are difficult experiments. We now feel, however, that the major problems have been solved.

6. Budget for Period May 1 to October 31, 1966:

Salaries	$6,470.00
Expenses	453.00
Capital Equipment	1,141.00
Total expenditures	$8,064.00

PROJECT A16

EXPERIMENTAL STUDIES OF ELECTRONIC AND IONIC COLLISIONS

1. Department: Physics and Astronomy

2. Principal Investigator: T. L. Bailey

3. Background: The overall aim of this research is to contribute to the basic understanding of atomic collision phenomena, and their role in space physics, by means of suitably designed particle beam experiments. Past research on this project has consisted of several types of collision experiments. Specifically, these are: (a) studies of the dynamics and energetics of ion-molecule reactions, of the general type $A^+ + BC = AB^+ + C$; (b) studies of collision-induced dissociation, for example, $D_2^+ + Ar = D^+ + D + Ar$; and (c) investigations of charge transfer of singly and doubly charged ions with neutral atoms and molecules. Two experimental apparati have been constructed for these studies, and are now in operation. These are: (1) an angular ion scattering apparatus, which gives detailed information regarding the energetics and dynamics of ion-neutral collisions; (2) a tandem mass spectrometer, which has been used primarily for measurement of total cross-sections for reactive ion-neutral collisions. A third apparatus, which will be rather simpler than the first two, and which will be used mostly for charge transfer studies, is now under construction. This research receives concurrent support from the Air Force Office of Scientific Research.

4. Progress from May 1 to October 31, 1966: Two papers, describing the earlier work on collision-induced dissociation, and on the ion-molecule reactions $Ar^+ + D_2 = ArD^+ + D$ and $N_2^+ + D_2 = N_2D^+ + D$, have been accepted for publication by the Journal of Chemical Physics (see publications).

The ion-molecule reaction studies have been extended to investigations of the reactions: (a) $D_2^+ + D_2 = D_3^+ + D$; (b) $D_2^+ + H_2 = D_2H^+ + H$; and (c) $D_2^+ + H_2 = H_2D^+ + D$. Distributions of product ions, in energy and in scattering angle, were determined over the primary ion laboratory kinetic energy range $2 \leq E_1 \leq 15$ eV. A number of conclusions have been drawn from these experimental results. D_3^+ appears to be formed via two distinct reaction channels: a pick-up process, in which the incident D_2^+ extracts a D atom from D_2, leaving behind a D atom which is approximately at rest in the laboratory system; and another pick-up

process, in which the target D_2 molecule extracts a D^+ ion from the projectile D_2^+. In the case of the $D_2^+ + H_2$ collisions, it appears that D_2H^+ is formed by pick-up of an H atom by the incident D_2^+ ion, and H_2D^+ apparently results from pick-up of a D^+ ion, from D_2^+, by the target H_2 molecule. In these collisions, ions of mass 1 and 2 were also observed. These are believed to be H^+, D^+, and H_2^+, which arise from dissociation of excited product ions. These reaction systems are certainly very interesting ones, in that reactions along so many different channels take place. The $D_2^+ + D_2$, $D_2^+ + H_2$ work is now being written up for publication in Journal of Chemical Physics.

The angular ion scattering apparatus has also been used recently in studies of charge transfer in collisions of doubly charged ions with neutral molecules, e.g., $Ar^{++} + H_2 = Ar^+ + (H_2^+)^*$. It was found in such collisions that the product Ar^+ ions were strongly forward-collimated in angle, with kinetic energy distributions which were typically about twice as broad as the primary ion profiles, and which had maxima at kinetic energies several eV above the mean energy of the primary ions. That is, the product Ar^+ ions on the average have greater kinetic energies than the primary Ar^{++} ions. This exceptional behavior comes about because of the Coulomb repulsion between the charged product ions. The angular scattering apparatus is capable of detecting only the fast, strongly forward-collimated, product ions. The other product ions [such as $(H_2^+)^*$, in the reaction cited above] are apparently scattered through such large angles that most of them escape detection, although small fluxes of both N^+ and N_2^+ were observed from collisions of Ar^{++} with N_2. Transfer has been observed in a number of collision systems: Ar^{++} and Ne^{++} in H_2, N_2, and O_2; and He^{++} in N_2. All of these reactions yield singly charged ions (Ar^+, Ne^+, or He^+) which have mean energies greater than that of the primary ions, and all of the transfer processes observed are exothermic. The reaction $He^{++} + N_2 = He^+ + (N_2^+)^*$ is especially interesting, since it presents a possible mechanism for escape of He species from the earth's atmosphere. If this reaction takes place at thermal energies (and this is not energetically forbidden, since the reaction is exothermic) it can yield fast He^+ ions, some of which would be directed away from the earth with velocities exceeding the escape velocity.

Total cross-sections for the transfer processes $Ar^{++} + H_2 = Ar^+ + H^+ + H$ and $Ar^{++} + N_2 = Ar^+ + [N^+ + N; (N_2^+)^*]$ have been determined over the primary ion kinetic energy range $5 \leq E_1 \leq 200$ eV, using the tandem mass spectrometer apparatus.[1,2] These measurements complement the studies of angular and energetic distributions described above.

5. Publications:

R. L. Champion, L. D. Doverspike, and T. L. Bailey, "Collision Induced Dissociation of D_2^+ Ions by Argon and Nitrogen," accepted for publication as article in Journal of Chemical Physics, December 15, 1966.

Publications Continued:

L. D. Doverspike, R. L. Champion, and T. L Bailey, "Energetic and Angular Studies of ArD^+ and N_2D^+ Formation," accepted for publication as article in Journal of Chemical Physics, December 15, 1966.

L. D. Doverspike and R. L. Champion, "Energetic Studies of Reactive Collisions for the Systems $D_2^+ + D_2$ and $D_2^+ + H_2$," presented at 19th Annual Gaseous Electronics Conference, Atlanta, October, 1966. Abstract to be published in Bul. Amer. Phys. Soc.

6. Budget for Period May 1 to October 31, 1966:

Salaries	$ 7,063.13
Expenses	2,068.82
Capital Equipment	6,581.95
Total expenditures	$15,713.90

7. References:

1. Vance, Dennis W. and Bailey, T. L., J. Chem. Phys., 44, 486, 1966.

2. Herrero, F. A. and Bailey, T. L., Bul. Amer. Phys. Soc., Series II, 11, 826, December, 1966.

PROJECT A17

NUCLEAR PROPULSION PROBLEMS

1. Department: Nuclear Engineering Sciences

2. Principal Investigator: Robert E. Uhrig

3. Background: This investigation is concerned with some of the peculiar problems associated with operation of nuclear reactors in space as a primary source of energy for propulsion and electrical power.

4. Progress from May 1 to October 31, 1966:

Adaptive and Optimal Control Systems. The first phase of this work on model reference adaptive control systems was completed by Major Jack T. Humphries, who wrote his Ph.D. dissertation at the University of Florida on "Model Reference Adaptive Control of a Nuclear Rocket Engine." Two papers which were an outgrowth of this dissertation have been presented at national meetings, as indicated below.

A second Ph.D. dissertation, entitled "Computational Techniques and Performance Criteria for Optimum Control of Nuclear System Dynamics," by J. K. Saluja, is nearing completion and Mr. Saluja will probably take his final examination within the next 30 days. This project involves the application of optimal control theory to the dynamic response of a nuclear rocket engine. The cost function used is an integral of the square of the total reactivity as the average core temperature is transferred from one steady state condition to another under the constraint that this cost function be minimized. Three problems are solved as examples of the application of this technique. These problems involve moving from one steady state to another state condition under the following conditions: (a) variable final time, (b) fixed final time, and (c) influence of parameter variation on system response. A paper entitled "Optimal Open and Closed-Loop Control of Nuclear System Dynamics" was presented at the winter meeting of the American Nuclear Society in Pittsburgh on November 1, 1966, and at least one additional paper is expected to be forthcoming from this work.

The third phase of the work involves nonlinear stability analysis of nuclear systems. This work is being carried out by Mr. Ira Thierer, presently a NASA trainee. The techniques associated with functional analysis and Volterra series solutions to integral

equations are being used to establish response and stability characteristics of a nuclear system. For the linear feedback case, absolute limits of stability have been determined by application of the properties of hypergeometric functions to the series representation of the system.

Of greater interest is the more general case of nonlinear feedback. Here a combination of functional analysis and nonlinear operator theory has been used to obtain a description of the nuclear system. The method is basically an extension of one-dimensional Laplace transform space to a multi-dimensional space. Work is continuing to establish stability criteria and time-dependent response from this type of system representation.

The project has been delayed due to the fact that the IBM-1800 digital computer and the associated linkage to connect it to the Applied Dynamics AD-80 analog computer have not been delivered as originally scheduled. The IBM-1800 was finally delivered about November 1, 1966 (1 year later) and is still undergoing check-out.

The necessary linkage to connect it to the AD-80 analog computer will not arrive until early 1967. However, with the arrival of this equipment, the Department of Nuclear Engineering Sciences will have a fine computational system ideally suited for the types of studies which have been undertaken over the past three years. The work presently under way will be continued, and additional projects in this area will be undertaken even though no additional funding was requested from the NASA grant after November 1, 1966.

Dr. Thomas Bullock, who holds a joint appointment with Nuclear Engineering Sciences and Electrical Engineering, is spending approximately half-time on work with the hybrid computer; and Dr. Andrew Sage, also a joint appointee between Nuclear Engineering Sciences and Electrical Engineering, has been working about quarter-time on this project.

5. Publications and Dissertation:

J. T. Humphries, R. E. Uhrig, and A. P. Sage, "Adaptive Control Concepts for Nuclear Rocket Propulsion Systems," AIAA Second Propulsion Joint Specialist Conference, Colorado Springs, Colorado, June 13-17, 1966.

J. T. Humphries, R. E. Uhrig, and A. P. Sage, "Model Reference Adaptive Control of a Nuclear Rocket Engine," IEEE Joint Automatic Control Conference, Seattle, Washington, August 17-19, 1966. Included in Proceedings of meeting.

Publications Continued:

J. K. Saluja, R. E. Uhrig, and A. P. Sage, "Computational Techniques and Performance Criteria for the Optimum Control of Nuclear System Dynamics," winter meeting of American Nuclear Society, Pittsburgh, Pennsylvania, November 1, 1966.

J. T. Humphries, "Model Reference Adaptive Control of a Nuclear Rocket Engine," Ph.D. Dissertation, University of Florida, April, 1966.

6. Budget for Period May 1 to October 31, 1966:

Salaries	$ 4,912.55
Expenses	-0-
Capital Equipment	14,874.00
Total expenditures	$19,786.55

PROJECT A19

PHOTOELECTRIC PHOTOMETRY OF VARIABLE STARS

1. Department: Physics and Astronomy

2. Principal Investigator: K-Y. Chen

3. Background: The study of variable stars at the University of Florida started in 1964. Most of the work has been observational, and the observed objects were mostly eclipsing variable stars. The 12.5-inch Newtonian reflector used at Gainesville, Florida is equipped with a photoelectric photometer and a strip-chart recorder, but the aperture limits the number of variable stellar systems which have not already been investigated in detail. Thus, during this report period, observations were made with larger instruments at Cerro Tololo Inter-American Observatory in Chile, and at Kitt Peak National Observatory in Arizona, besides the continuous work at the University of Florida.

4. Progress from May 1 to October 31, 1966:

A. Observations. University of Florida: R. B. Carr, Research Assistant, made observations of the eclipsing binary HD 151676, but there are not yet enough data to complete the light curve.

Cerro Tololo: During the period from April 25 to May 14, K-Y. Chen observed two eclipsing binaries, BV 513 and BV 419, using one of the 16-inch reflecting telescopes. Data were obtained in three colors (UBV) for complete light curves of these stars. The periods of these variables are observed to be 0.74 day for BV 513 and 0.63 day for BV 419, indicating that the reported periods of 0.424 day for BV 513 and 0.478 day for BV 419 were in error. A comparison star was discovered to be variable during the investigation; it was identified as HD 116994. The period of this new variable was found to be 0.104 day. This star most likely belongs to the group of dwarf cepheids.

Kitt Peak: Using one of the 16-inch reflecting telescopes, R. B. Carr observed the two eclipsing binaries, CZ Aquarii and UV Piscium, in three colors during the period from September 15 to October 30. The observed data for complete light curves will be analyzed for his doctoral dissertation.

B. Reduction of Data and Analysis. Computer programs are being compiled for future data reduction and analysis. Data obtained as mentioned above are being reduced.

C. Search for Observatory Site for New 30-inch Telescope. A 30-inch Newtonian-Cassegrain telescope is being built by the Tinsley Laboratory, Inc., funds for the telescope having been provided from a $4.2 million National Science Foundation Science Development Grant. Dr. J. K. Gleim, Assistant Professor of Astronomy, and K-Y. Chen have located several sites 25 miles southwest of Gainesville suitable for the new observatory. Acquisition of the land is now being handled by the business office of the University.

5. Publication:

K-Y. Chen, "Photoelectric Observation of HD 116994," I.A.U. Information Bulletin on Variable Stars, 142, 1966.

6. Budget for Period May 1 to October 31, 1966:

Salaries	$2,950.00
Expenses	1,104.00
Capital Equipment	420.00
Total Expenditures	$4,474.00

PROJECT A22

HYDROTHERMODYNAMICS OF LAMINAR JETS

1. Department: Aerospace Engineering

2. Principal Investigator: K. Millsaps

3. Background: One of the classical situations in fluid dynamics is the laminar flow of a fluid through an opening into the same fluid which has no secondary motion or, to be relatively more precise, an analytical description of the flow resulting from the continuous application of a force along a line in a fluid medium. It is traditional to refer to the situation as the plane jet.

In case of the plane jet, Schlichting reduced the boundary layer equations to an ordinary differential equation, which he then treated by continuous joining of a power series from the origin with an asymptotic expansion: unfortunately, Schlichting also made some numerical errors. Bickley in a truly remarkable paper then showed that the involved treatment by Schlichting was unnecessary, by exhibiting a closed form solution to the ordinary differential equation in terms of hyperbolic functions. Yih used Bickley's solution to treat with a similarity transformation the associated heat transfer problem, in which the usual thermal boundary layer assumptions are made and in which all effects due to viscous dissipation are neglected. The attempted experimental verification of the hydrodynamics by Andrade yielded only "tolerably good results," and in view of the philosophical stakes it seems that another attempt at an admittedly difficult experiment would be worthwhile. As far as is known, reliable data on the heat transfer problem do not exist.

In previous progress reports it has been noted that Millsaps and Soong completed an exact treatment of the thermal boundary layer problem that had previously been attempted by Yih, and, as conjectured, they demonstrated that the solution by Yih was erroneous. Galley proofs on an article reporting this theory have recently been corrected, and publication is scheduled for February, 1967, in the Blanch Anniversary Volume.

Experiments with the objective of verification of the velocity and temperature profiles are being performed, although it is exceedingly difficult to reproduce the required conditions in the laboratory.

4. Progress from May 1 to October 31, 1966: Regarding progress on the theoretical analyses, Millsaps and Soong (Physics of Fluids, Volume 8, 200, 1965) have shown in the case of a round jet that it is possible to reduce the energy equation to an ordinary differential equation by a similarity transformation, using the exact solution of the Navier-Stokes equations due to Landau. The resulting ordinary differential equation is a "rough" one and has resisted all attempts, even for selected Prandtl numbers for analytical and/or semi-analytical treatment; moreover, because of the singularities, even numerical solutions have not been obtained. We have not succeeded; we will try and try again.

Regarding progress on the experimental measurements, we have succeeded in producing an extremely long stable plane jet, from 6" to 10", or about 60 to 100 times as long as the width of the slit. Our attempts at a precise determination of the velocity profiles have been frustrated by thermal convective currents which are induced by the heat from the required illumination. We have attempted to use pulsed lasers as sources of illumination, but those lasers currently available to us did not have sufficient output power. It now appears that a redesign of our light source is necessary, although it should be noted that our present measurements of the velocity profiles are quite as good as the classical ones due to Andrade.

5. Budget for Period May 1 to October 31, 1966:

Salaries	$3,623.60
Expenses	540.93
Capital Equipment	324.16
Total Expenditures	$4,488.69

PROJECT A23

HYPERBARIC OXYGEN AND AGING

1. Department: Radiology

2. Principal Investigator: H. L. Cromroy

3. Background: The basic aim of this research is to determine whether there is any synergistic effect between prolonged hyperbaric oxygenation and other physical insults such as ionizing radiation.

In addition, certain biochemical tests will be run with prolonged partial pressure (0.5 atmosphere) of 100% oxygen environment to determine if any detrimental effects occur from the hyperbaric situation alone. We have started our work with nuclear volume sizing in mammals, nuclear oxidative phosphorylation studies in rats, and development of oxygen tension electrodes which will do "in vivo" measurements.

A major problem has been the selection of a hyperbaric chamber which would be adaptable to a wide scale of tests and would fit our space requirements. A chamber has been ordered with temperature and humidity control, a range of pressures from 5 PSIA to 150 PSIA, and which permits food to be administered while animals are under pressure and waste to be removed. The current estimated date of delivery is the end of November, 1966.

4. Progress from May 1 to October 31, 1966: We have carried out considerable preliminary research prior to the chamber's arrival. One set of experiments dealt with effects of low total body exposures of ionizing radiation on nuclear oxidative phosphorylation in rat thymocytes. Our data indicate that an effect does occur at 100R and 200R total body exposure. This biochemical lesion, produced at a relatively low dose, appears to us to be a good indicator for our dual insult studies. We have also done a series of sizing studies on intestinal epithelial cells of mammals, and attempted to relate this to their relative radiosensitivity. We wish to see if nuclear volume changes under prolonged hyperbaric conditions. Our work on microelectrodes has moved rather slowly, since there were many problems. We can now fabricate the electrodes and have settled on a suitable electronic amplifier for our signals. At present, we have purchased most of the electronic "hardware" for physiological measurements to be made on animals in the chamber.

5. Talks presented at Southeastern Chapter of the Society of Nuclear Medicine at Durham, North Carolina, November 3-5, 1966:

D. Zimmerman and H L. Cromroy, "Radiation Effects on Rat Thymus Nuclei."

A. Porter, A. Burns, and H. L. Cromroy, "A Relationship between Interphase Chromosome Volume and Radiation Sensitivity in Mammalian Species."

6. Budget for Period May 1 to October 31, 1966:

Salaries	$ 1,292.90
Expenses	142.46
Capital Equipment	10,961.45
Total Expenditures	$12,396.81

PROJECT A24

EXPERIMENTS ON MECHANISM OF COLOR VISION

1. Department: Aerospace Engineering

2. Principal Investigator: Orlo E. Myers

3. Background: The importance of visual judgment in any manned space venture is clearly recognized, yet many aspects of the visual process are only poorly understood. As a result, it is not now possible to predict human behavior in a given extraterrestrial situation.

A systematic approach toward better understanding of the mechanism of visual and cerebral perception logically begins with understanding the primary light absorption process. Light from the surrounding environment, held in focus on the retina by higher-order neuromuscular activity, encounters a mosaic of visual cells whose physical properties influence propagation into their outer segments where absorption initiates perceptive neural activity.

Mathematical techniques have not been developed to permit a knowledgeable description of the behavior of electromagnetic radiation under such circumstances. Solution of Maxwell's equations for such boundary conditions has been attempted by Jones, with moderate success, by casting the problem into an integral equation using a dyadic Green's function. Preliminary calculations, based upon "pseudo-modes" for propagation along irregular dielectric cylinders, support the idea that coupling among the elements of a two-dimensional array -- viz. "cone" cells -- is significantly different from the progression of a plane wave, as has been invariably assumed by physiologists. Physiologists have established that cones are responsible for hue discrimination. A distribution of their sizes and shapes, logical on physiological grounds, are now known to be sensitive to wavelength and might account for the mediation of color vision.

It is the purpose of this project to develop suitable mathematical techniques for analyzing mosaics of "light pipes," and to test the significance of the several possible assumptions which would permit analysis of the behavior of light in the retina. Because dimensions scale directly with wavelength if refractive indices are unchanged, microwave radiation may be used to verify mathematical assumptions.

During the first six months of this project, the principal equipment was acquired to proceed with microwave verification, techniques were developed for measurement of refractive index, and a computer program was devised to obtain the characteristics of the six lowest propagable modes of an arbitrary cylindrical dielectric waveguide.

4. Progress from May 1 to October 31, 1966: The computer program has been modified to compute K_0/K_1 whenever the argument of the Bessel function, modified, of the second kind, exceeds 4.51, because, at this point, the semi-convergent series for K_0/K_1 provides greater accuracy.

Techniques have been devised for reliable measurement of refractive index. It has been determined that the least expensive plastic -- low-density polyethylene -- may be used in an experimental retina, immersed in mixtures of mineral oil, CCl_4, gasoline, and paraffin, and that these "interstitial media" will be non-hazardous.

Two identical modular "cones" have been prepared for testing. However, a void was discovered, by chance, in machining the second "cone" outer segment. Since voids could vitiate the microwave experimental results, it is now planned to x-ray the entire stock of plastic.

5. Budget for Period May 1 to October 31, 1966:

Salaries	$ 110.86
Expenses	179.73
Capital Equipment	1,733.82
Total expenditures	$2,024.41

PROJECT A25

TURBULENT DIFFUSION OF HEAT AND MASS

1. Department: Chemical Engineering

2. Principal Investigators: R. W. Fahien and D. W. Kirmse

3. Background: The prediction of heat and mass diffusion rates in turbulent flows is a fundamental problem of the space-related sciences. An approach to the study of turbulent transport is to express the diffusive fluxes in terms of eddy diffusivity and conductivity tensors:

$$J_A^{(t)} = -\underline{\underline{E}} \cdot \nabla C_A \qquad q^{(t)} = -\underline{\underline{K}} \cdot \nabla T$$

The use of a tensor, rather than a scalar diffusivity and conductivity as applies to molecular transport, is necessitated here by the anisotropy of the turbulent dispersion processes.

The components of $\underline{\underline{E}}$ and $\underline{\underline{K}}$ are functions of the physical properties of the fluid and the geometry of the flow field, and have been experimentally investigated as functions of position and Reynolds numbers for restricted systems. An objective of this investigation is the prediction of these quantities for an arbitrary system strictly from theoretical considerations and statistical parameters obtained by hot wire anemometery measurements of velocity fluctuations. Pioneering work was done toward this end by G. I. Taylor, who suggested a random walk description of the motion of a fluid element.

4. Progress from May 1 to October 31, 1966: A primary research effort has been the development of a general stochastic model to describe the combined eddy and molecular dispersion of thermal energy. Models based on a random walk procedure were developed in the earlier research efforts. However, the development of specific simulation procedures which provide efficient computational algorithms is being continued.

Monte Carlo techniques are used to simulate the random flight of a fluid element in a turbulent field. The fluid element loses or gains thermal energy by molecular diffusion according to the local thermal state of the flow field the element is passing through. The model and accompanying computational algorithm allow variable heat sources and flow conditions to be specified. This is a major extension of an earlier model of the present authors, which simulates mass diffusion from point sources assuming no molecular transport.

Still in progress is a comparison of available heat transfer data for certain turbulent flow regions to the heat transfer predicted by the model. The heat transfer in open fluid flow can be readily predicted by the model and is compared to the results of Kistler, et al. (NACA RM 58019, 1954), and Uberoi and Corrsin (NACA Report 1142, 1953), for isotropic turbulence. With mass transfer the solid surfaces contacting the fluid can be considered as impermeable; that is, no mass transfer occurs across the solid-fluid interface. With thermal energy transport the surface can act as a source or sink. The stochastic model does represent the heat transfer at the boundaries, but the development of a satisfactorily efficient computational procedure has proven difficult. The surface heat transfer predictions of the models are being compared with the boundary layer data of Reynolds, et al. (NASA memo 12-1-58 W, 12-3-58 W, and 12-3-58 W).

A program is being written for the 709 IBM digital computer to investigate the eddy conductivity tensor for parallel plate flows. The values of the tensor components are statistically determined by stratified sampling of the simulated fluid motion and heat transfer. A comparison of the predicted thermal transport with the experimental data of Schlinger, et al. (Ind. and Eng. Chem., 45, 662-666, 1953) will be made. The interactions of molecular and turbulent diffusion will be investigated by a direct comparison of the effect of molecular diffusivity on the overall rate of thermal energy transport as predicted by the stochastic model. And, if the effects of molecular transport can be assumed negligible, the Eulerian-Lagrangian velocity relationship will be inferred from a comparison of Schlinger's data and the turbulent diffusion model simulations.

5. Publication:

D. W. Kirmse and R. W. Fahien, "Monte Carlo Prediction of Radial Axial, and other Components of the Eddy Diffusivity Tensor in Tubes," accepted paper, American Institute of Chemical Engineers national meeting, Salt Lake City, Utah, May, 1967.

6. Budget for Period May 1 to October 31, 1966:

Salaries	$ 3,910.84
Expenses	122.84
Capital Equipment	6,636.66
Total Expenditures	$10,670.34

PROJECT A26

NONSTATIONARY NONLINEAR DYNAMIC PROCESSES

1. Department: Electrical Engineering

2. Principal Investigator: A. P. Sage

3. Background: The goal of this research has been the development of practical computational procedures for the determination of unknown parameters in, as well as the modeling and control of, nonlinear dynamic systems.

4. Progress from May 1 to October 31, 1966:

A. A Technique for the Real Time Digital Simulation of NonLinear Control Processes. This research illustrated a method for the digital simulation of linear and nonlinear control systems with large sampling intervals. An optimization criterion for determining the "best" approximation to elements of a continuous control system was presented. The "best" approximation is defined as the realizable approximate transfer function that minimizes the sum of error squared between the continuous output and the actual discrete output. In order to obtain this, it was necessary to solve a nonlinear multi-point boundary value problem. The technique of quasi-linearization was used to reduce the nonlinear boundary value problems to a converging sequence of linear boundary value problems that are not difficult to solve on a digital or hybrid computer. It was shown that the large sampling intervals obtainable by this method make it attractive for the real time digital simulation of control processes.

B. Real Time Identification of Dynamic Processes by Sequential Estimation. It is desirable to develop a method for the identification of nonlinear and time varying systems which does not require assumptions concerning the statistical nature of the input disturbances or measurement errors. This is particularly true since determination of valid statistical data concerning disturbances in noisy, nonlinear systems is in itself an extremely difficult problem. The usual classical approach to least squares estimation schemes leads to nonsequential estimations, in that each time an additional output observation is included, the entire least squares calculation must be repeated. Some sequential estimation schemes have been devised, but many questions still remain concerning state vector component selection. The developed scheme uses Pontryagin's Maximum Principle

to write a set of canonic equations for the minimization of the integral of weighted squared residual estimation errors. The technique of invariant imbedding is then used to obtain the computational algorithms for sequential estimation.

In the course of this investigation, it has become clear that two auxillary areas of investigation would greatly enhance the capability of the identification schemes that have been under investigation. These would also complement the identification effort in that the combined identification, modeling, and control of nonlinear dynamic processes would allow the complete closed loop design of a form of optimum adaptive control.

5. Publications:

W. C. Choate and A. P. Sage, "A Useful Change of Variable for a Class of Linear Differential Systems," IEEE Trans. on Automatic Control, October, 1966.

A. P. Sage and S. L. Smith, "Real Time Digital Simulation for Systems Control," Proceedings, IEEE, in press for December, 1966.

A. P. Sage and G. W. Masters, "On Line Estimation of States and Parameters for Discrete Nonlinear Dynamic Systems," Proceedings National Electronics Conference, October, 1966.

A. P. Sage and G. W. Masters, "Identification and Modeling of States and Parameters of Nuclear Reactor Systems," IEEE Trans. on Nuclear Science, in press for February, 1967.

A. P. Sage and B. R. Eisenberg, "Suboptimal Adaptive Control of a Nonlinear Plant," IEEE Trans. on Automatic Control, July, 1966.

J. R. Humphries, R. E. Uhrig, and A. P. Sage, "Adaptive Control Concepts for Nuclear Rocket Propulsion Systems," Proceedings AIAA Joint Propulsion Specialists Conference, June, 1966.

A. P. Sage and T. W. Ellis, "Sequential Suboptimal Adaptive Control of Nonlinear Systems," Proceedings National Electronics Conference, October, 1966.

B. R. Eisenberg and A. P. Sage, "Closed Loop Optimization of Fixed Configuration Systems," International Journal on Control, 3, 1966.

A. P. Sage and T. W. Ellis, "Optimal and Suboptimal Guidance and Control for Low Thrust Orbital Transfer," Proceedings, Symposium on Missile and Aerospace Vehicle Sciences, American Astronautical Society, 1966.

6. Budget for Period May 1 to October 31, 1966:

Salaries	$7,970.00
Expenses	1,000.00
Total Expenditures	$8,970.00

PROJECT A27

SCATTERING OF ALKALI METALS IN HIGH INTENSITY MOLECULAR BEAMS

1. Department: Chemistry

2. Principal Investigator: S. O. Colgate

3. Background: This program is concerned with inferring information about the magnitude of the pair-wise intermolecular potential from measurements of the scattering occurring where a beam of alkali atoms traverses a gas-filled region. Total elastic scattering cross sections are measured as functions of the alkali beam energy. The latter is controlled by mechanical velocity selection.

The intermolecular potential energy describing the interaction between two spherically symmetric atoms or molecules is known to represent a net attraction for relatively large values of the separation distance R, and a net repulsion for relatively small values of R. The parameters in a convenient (but arbitrary) assumed form of the potential can often be fixed from the results of a single experiment. The function thus obtained, however, is not an accurate representation of the potential for all values of R unless, of course, the assumed form happened to be the true form. Indeed, each experiment is primarily influenced by interactions of a particular kind, e.g., weak attraction, strong attraction, strong repulsion, etc., and it is only for values of R corresponding to the appropriate interaction region that deduced potential energy functions may be considered to be reliable.

In principle, molecular beam experiments can be designed to provide potential information for various regions of R. If the relative kinetic energy of the colliding molecules is large, the distance of closest approach is correspondingly small, and the change in direction of relative motion is primarily determined by the short range repulsive forces. On the other hand, for low-energy interactions the molecules may not approach each other close enough for the repulsive forces to contribute significantly, and only part of the longer range attractive potential may be determined. The present experiments are of the latter kind, and the interpretations are made using the Landau-Lifschitz partial wave treatment of the scattering phenomenon.

4. Progress from May 1 to October 31, 1966: During the grant period a new McLeod gauge was invented, constructed and tested. This instrument eliminates the errors due to pumping of the gauge volume

by mercury vapor streaming from the reservoir to the cold trap. Other means have been devised and used recently in other laboratories, but the present system is substantially simpler to build and operate. All of the inert gases were calibrated with the new gauge, and the errors which would have resulted from the mercury streaming were measured. These results were consistent with published corrections obtained with more elaborate equipment.

Experiments on the scattering of cesium into inert gases (all except xenon) were performed, and the data were analyzed in terms of the new pressure calibrations. As anticipated earlier, the resulting parameters in the pair-wise potentials of the form $U(r) = Cr^{-6}$ all lie near the theoretical estimates of Dalgarno. Because the scatter of values was higher than has previously been observed, some of the measurements are currently being repeated under conditions suitably modified to reduce the random scatter. The system Cs-Xe is also to be studied.

5. Publications: No reports on this work were submitted for publication during this period. A paper describing the improved McLeod gauge is planned.

6. Budget for Period May 1 to October 31, 1966:

Salaries	$1,350.00
Expenses including computing	756.47
Capital Equipment	6.971.57
Total Expenditures	$9,078.04

PROJECT A28

ASTRONOMICAL INVESTIGATIONS OF THE GRAVITATIONAL FIELD

1. Department: Physics and Astronomy

2. Principal Investigator: Guy C. Omer, Jr.

3. Background: The fundamental problem is the nature of the gravitational field. In particular, evidence is being sought for the existence or the non-existence of the cosmological constant in Einstein's field equations of general relativity. Some limits can be set on the value of the cosmological constant by fitting relativistic models to the entire universe. More exact determination is being sought in the clusters of galaxies. A cluster of galaxies is dimensionally large enough so that non-Newtonian departures from an exact inverse-square law of gravitational attraction should be detectable. A cluster of galaxies is also astronomically small enough so that most of its significant parameters can be determined.

4. Progress from May 1 to October 31, 1966: Calculations have been begun with the University of Florida IBM 709 computer, in which non-homogeneous zero-pressure relativistic models of the universe are constructed where a cluster of galaxies at the center issuperimposed upon a homogeneously expanding universe. The model now fitted agrees with the counts of galaxies made earlier in the Coma Cluster (A.J., 70, 440) under the assumptions that the average mass of a cluster galaxy is about 6×10^{11} solar masses, the age of the universe is about 2×10^{10} years, the average density of matter at infinity is about 10^{-30} gm/cc, and the entire model is expanding monotonically. This first model is not satisfactory, since it was found that very slight changes in the constants near the center of the cluster would make great differences in the computed ages. This would not make good physics. The new generation of models will have oscillating cluster cores connected smoothly to a monotonically expanding cluster periphery and the rest of space. Only rough calculations of these new models have been made at present. An IBM program is yet to be developed. It is hoped that the transition point between the oscillating and the monotonically expanding parts of the cluster model will indicate a probable value for the cosmological constant.

The principal investigator spent part of August at the Mt. Palomar Observatory using the 48-inch Schmidt telescope. A series of 10" x 10" plates were taken to include the following clusters of galaxies: Abell 2199, Abell 2065, Abell 2255, Abell 2256, Abell 2151, and Abell 168. These six clusters where chosen because of their position in the August sky, their approach to spherical

symmetry, and because most of them are low-frequency radio emitters. The first two clusters are the most important, and are each covered by three plates: one long-exposure plate in the red and two shorter-exposure plates in the blue. The remaining clusters are covered by single blue plates.

The plates for the first cluster of galaxies, Abell 2199, are now being counted. The theoretical models for a cluster of galaxies have been fitted to a density distribution curve derived from the counts of galaxies in the Coma Cluster. Of particular interest in these models has been an apparent point of inflexion at about two-thirds of the cluster radius. A small positive cosmological constant is being postulated to explain this presumed structure. But it is always possible that this point of inflexion is unique to the Coma Cluster and is not an universal feature of all clusters of galaxies. This is why it is important to count other clusters of galaxies. Abell 2199 has additional interest since the peculiar galaxy Arp 125 (with its two associated quasars 3C332 and 3C345) is located just outside our plate boundary. This peculiar galaxy has the same red-shift as the cluster and might possibly be a member of the cluster. This can be ascertained only by careful counting to determine the probable cluster boundary.

Collaboration has been begun with Professor T. D. Carr for radio surveys of the clusters of galaxies. The low-frequency contour map published by Large, Mathewson, and Haslam (Nature, 183, 1664) for the Coma Cluster shows many features in common with the unpublished optical contour map of this same cluster made by Omer and Page. Tentative calculations by Professor Carr indicate that all of the low-frequency energy might be accounted for by the 800 galaxies assigned to this cluster by Omer, Page, and Wilson (A.J., 70, 440). This would be an important conclusion if it can be substantiated. Further radio work at different frequencies is now being planned over the Coma Cluster. Similiar radio surveys will be made over Abell 2199 when the optical counts are completed. Each of the other five clusters now available on Palomar Schmidt plates may also be investigated by the methods of radio astronomy. The primary question whose answer is being sought is the presence or absence of intergalactic material in the clusters.

5. Publications:

Guy C. Omer, Jr. and James P. Vanyo, "Closed Model Universes With a Cosmological Constant," The Astrophysical Journal, 145, 555, 1966.

Guy C. Omer, Jr., "The Distribution of the Brighter Galaxies in the Coma Cluster," (Abstract), The Astronomical Journal, 71, 394, 1966.

6. Budget for Period May 1 to October 31, 1966:

Salaries	$3,060.00
Expenses	633.00
Capital Equipment	2,065.00
Total expenditures	$5,758.00

LIST OF PUBLICATIONS SUBMITTED TO NASA DURING THE REPORT PERIOD

Project A02

"The Radio Rotation Period of Jupiter," S. Gulkis and T. D. Carr, Science, 154, 257, 1966.

"Asymmetrical Stop Zones in Jupiter's Exosphere," S. Gulkis and T. D. Carr, Nature, 210, 1104, 1966.

Project A03

"Influence of the Terrestrial Environment on the Temporal and Statistical Characteristics of Jovian Decametric Radiation," A. G. Smith, W. F. Block, W. A. Morton, G. R. Lebo, T. D. Carr, and C. N. Olsson, Radio Science, 1 (New Series), 1167-1171, 1966.

"Jovian Rotation Periods and the Origin of the Decametric Burst Structure," A. G. Smith, G. R. Lebo, C. N. Olsson, W. F. Block, N. F. Six, and T. D. Carr, Proceedings of CAL/TECH-JPL Lunar and Planetary Conference, California Institute of Technology, 128-133, 1966.

Project A05

"Nuclear Levels in Sulfur Excited by the (He^4, γ) Reaction," P. N. Carlton and F. E. Dunnam, Bul. Amer. Phys. Soc., 11, 737, 1966 (Abstract).

"Level Structure in Ar^{36} and Ar^{38} from the $S^{32,34}$ $(He^4, \gamma)Ar^{36,38}$ Reactions," F. E. Dunnam and P. N. Carlton, Bul. Amer. Phys. Soc., 11, 737,1966 (Abstract).

Project A13

"Variational Method for the Ground State of Liquid He^4," J. C. Lee and A. A. Broyles, Phys. Rev. Letters, 17, 425, 1966.

"Electric Microfield Distributions in Plasmas," C. F. Hooper, Jr., Phys. Rev., 149, 77, 1966.

Project A19

"Photoelectric Observations of HD116994," K-Y. Chen, IAU Information Bulletin on Variable Stars, 142, 1966.

Project A28

"Closed Model Universes With a Cosmological Constant," Guy C. Omer, Jr. and James P. Vanyo, Astrophys. J., 145, 555, 1966.

"The Distribution of the Brighter Galaxies in the Coma Cluster," Guy C. Omer, Jr., Astron. J., 71, 394, 1966 (Abstract).